Radar Systems and
Remote Sensing Laboratory

FINAL TECHNICAL REPORT

Radar Backscatter from the Sea: Controlled Experiments

ONR GRANT N00014-90-J-4044

THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
2291 Irving Hill Road
Lawrence, Kansas 66045-2969

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R. K. Moore

Radar Systems and Remote Sensing Laboratory
University of Kansas Center for Research, Inc.
2291 Irving Hill Road
Lawrence, Kansas 66045-2969
913/864-4835
FAX: 913/864-7789 * OMNET: KANSAS.U.RSL * TELEX: 706352

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Richard K. Moore, PI

This grant was to (1) complete analysis of University of Kansas data from the SAXON-CLT experiment, (2) compare these scatterometer results with simultaneous radar measurements by other experimenters, and (3) compare real- and synthetic-aperture images with each other and with tower data. The first two tasks were to be performed at the University of Kansas and the third at Oklahoma State University. Because of problems in meeting the second and third objectives, the effort was redirected to general analysis and synthesis tasks and to help in analysis of SAXON-FPN data.

We could complete only objective (1), as explained below. The Kansas scatterometer measurements were from the south side next to the southwest corner of the CLT. We chose this location because climatological data showed that prevailing winds were normally from the south and southwest. Unfortunately, during the CLT experiments the winds never came from these directions. The result is corruption of l data by the wind/wave shadow of the tower. Consequently, we believe that wind-response and modulation data are of little value. We processed the best of these downwind runs for MTFs and found the phases to be roughly as expected for downwind. We believe that sea-spike data may be more useful even in this unfortunate situation. Hence, we will present these results, along with those from SAXON-FPN, at the URSI Specialist Symposium on Microwave Signatures in Igls, Austria, in July, 1992.

Visits to MIT and the University of Massachusetts showed that no measurements were made by these groups at the same time as our good runs. We did not obtain any data from them. Hence, we could not meet objective (2).

Completion of the Oklahoma State work on objective (3) was impossible because the images were never delivered. Consequently, that effort took the form of a continuing study of the theory of imaging of ocean waves by SAR. Several significant papers resulted on SAR imaging theory and estimation of wave spectra from SAR images.

Results of the analyses appear or will appear in a set of papers outlined in the attached publication list. Although we could not meet the initial objectives, we feel that the grant supported much useful research, as shown by the papers published, presented, or in press.

FINAL REPORT ON

"RADAR BACKSCATTER FROM THE SEA-- CONTROLLED EXPERIMENTS"

James C. West, Co-Principal Investigator
School of Electrical and Computer Engineering
Oklahoma State University, 202 ES
Stillwater, OK 74078

This is the final report on work performed at Oklahoma State University under the University of Kansas Center for Research subcontract 8960-90, primary contract Office of Naval Research N00014-90-J-4044. The work performed is documented in the publications listed below. A short summary of the results is given here.

The subwindowing method of modelling synthetic-aperture-radar (SAR) imaging of ocean waves was extended to allow wave propagation in arbitrary directions. Simulated images show that the SAR image response to swells that are imaged by velocity bunching is reduced by random smearing due to wind-generated waves. The magnitude of this response is not accurately predicted by introducing a finite coherence time in the radar backscatter. The smearing does not affect the imaging of waves by surface radar cross-section modulation, and is independent of the wind direction. Adjusting the focus of the SAR processor introduces an offset in the image response of the surface scatters. When adjusted by one-half the azimuthal phase velocity of the wave, this compensates the incoherent advance of the wave being imaged, leading to a higher image contrast. The azimuthal cut-off and range rotation of the spectral peak are predicted when the imaging of wind-generated wave trains is simulated. The simulated images suggest that velocity bunching and azimuthal smearing are strongly interdependent, and cannot be included in a model separately.

Simulated SAR images of fully saturated, azimuthally propagating wind-generated wave spectra were generated using parameters typical of a spaceborne SAR, but with varying platform range-to-velocity (R/V). Maximum image spectral signal-to-noise ratio was obtained with an R/V of 50 s, somewhat higher than is usually suggested as optimal for imaging of azimuthal wind waves. Although the azimuthal smearing is greater at the higher R/V, the corresponding increase in velocity bunching modulation is more significant due to imaging nonlinearities. If the nonlinear spectral inversion techniques currently being developed (Hasselmann and Hasselmann, 1991, *J. Geophys. Res.*, **96**, 10,713-10,729) prove successful, a better measurement of the surface wave spectrum would likely be obtained using the higher R/V.

Methods of estimating the spectra of multi-look SAR images of ocean waves were examined. The resulting spectral signal-to-noise ratio was found to be unaffected by the detection scheme (linear or square-law) used in incoherently combining the individual looks. A new method of registering the looks before incoherent combination, termed spectral-phase-shift processing, was developed. This technique registers the wave energy at all wave numbers, rather than at only a single wave number as in traditional techniques. Using spectral-phase-shift processing, the spectral signal-to-noise ratio is improved at all wave numbers and the 180° ambiguity in the propagation direction is partially resolved.

Because experimental images were not available, the comparison of the SAR and RAR images of waves from the SAXON-CLT experiment was not conducted.

Publications and Presentations

West, J. C., Two-dimensional modeling of synthetic-aperture-radar of ocean waves using subwindowing technique, *Int. J. Rem. Sens.* vol. 13, no. 4, 615-636, 1991.

Vachon, P. W. & J. C. West, Spectral estimation techniques for multilook SAR images of ocean waves, submitted 1991 to *IEEE Trans. on Geosc. & Rem. Sens.*, under review.

West, J. C., The effect of range-to-velocity ratio on SAR imaging of azimuthal ocean waves, accepted April 1991 for publication in *IEEE Trans. on Geosc. & Rem. Sens.*

Haimov, S., V. Hesany & R. K. Moore, Autoregressive modeling for ocean wave-radar modulation transfer function, submitted to *J. Geophys. Res.* April 1992.

Haimov, S., V. Hesany & R. K. Moore, Autoregressive modeling for ocean backscatter analysis, accepted for presentation at Microwave Signature'92 Conference to be held in Igls, Austria, 1-3 July 1992.

Moore, R. K., Surface wind-vector measurements with spaceborne scatterometers: results, plans and background, Joint US/USSR Workshop on Satellite Oceanography, (sponsored in US by Nat'l Council for Research), USSR, June 1991.

Moore, R. K., Some recent improvements in understanding radar imaging based on tower experiments and theory, Joint US/USSR Workshop on Satellite Oceanography, (sponsored in US by Nat'l Council for Research), USSR, June 1991.

West, J. C., Numerical prediction of the effects of azimuthal smearing on SAR imaging of ocean waves using the subwindowing technique, *DIGEST IGARSS'91,* IEEE 91CH2971-0, Espoo, Finland, 3-6 June 1991, 1621-1624.

West, J. C. & W. Vachon, Spectral estimation techniques for multilook SAR images of ocean waves, *DIGEST IGARSS'91,* IEEE 91CH2971-0, Espoo, Finland, 3-6 June 1991, 459.